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Low temperature heat capacity of $YBa_2Cu_3O_7$

N NAMBUDRIPAD and S K DHAR
Tata Institute of Fundamental Research, Bombay 400 005, India

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Abstract. We have measured the heat capacity of superconducting, single phase $YBa_2Cu_3O_7$ in the temperature range 2 to 18 K. An extrapolation of the data between 4 and 9 K gives a $C/T(T \rightarrow 0)$ of ~ 25 mJ/mole K^2. The Debye temperature obtained from the high temperature linear portion of C/T vs T^2 plot is 325 K.

Keywords. High temperature superconductors; Y-Ba-Cu-O system; heat capacity measurements.

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The recent discovery of high temperature superconducting oxides has led to intense research activity on these interesting, technologically promising materials. Bednorz and Muller (1986) first reported the possible occurrence of superconductivity in the 30 K range in the multiphase system $La_{5-x}Ba_xCu_5O_{5(3-y)}$. This observation soon received confirmation from other groups and the phase responsible for superconductivity was identified as $La_{2-x}Ba_xCuO_4$, crystallising in the tetragonal K_2NiF_4 structure type (Chu *et al* 1987; Uchida *et al* 1987). Subsequently, Wu *et al* (1987) reported superconductivity in the 90 K range in the multiphase $Y_{1\cdot2}Ba_{0\cdot8}CuO_{4-y}$. It is now established that the compound $YBa_2Cu_3O_7$, an orthorhombically distored perovskite, undergoes a transition to the superconducting state at 90 K (Ganguly *et al* 1987; Dhar *et al* 1987; Cava *et al* 1987). Surprisingly, the replacement of non-magnetic Y by magnetic rare-earth ions such as Gd, Er, Sm, etc does not have any perceptible effect on the superconducting transition temperature (Fisk *et al* 1987). In this communication, we report the low temperature, 2 to 18 K, heat capacity measurements on $YBa_2Cu_3O_7$.

The sample used in the present work has been studied earlier by magnetic susceptibility and electrical resistivity techniques (Dhar *et al* 1987) and has a transition temperature of 90 K. Heat capacity measurements were carried out using a recently built calorimeter which works in the temperature range 1·5 to 25 K (Nambudripad and Dhar 1987). A semi-adiabatic heat-pulse method is employed and the temperature is measured with a calibrated germanium resistance thermometer. In order to check the accuracy of the data obtained from our set-up, we measured the heat capacity of 99·999% pure samples of tin and indium, which are both superconducting with transition temperatures accessible in the temperature range of our measurements, and we find good agreement (to within 2%) with the data existing in the literature (Bryant and Keesom 1960; Corak and Satterthwaite *et al* 1956).

Figure 1 shows the heat capacity of $YBa_2Cu_3O_7$ plotted as C/T vs T^2 in the temperature range 2 to 18 K. There is an upturn of C/T at the lower temperatures

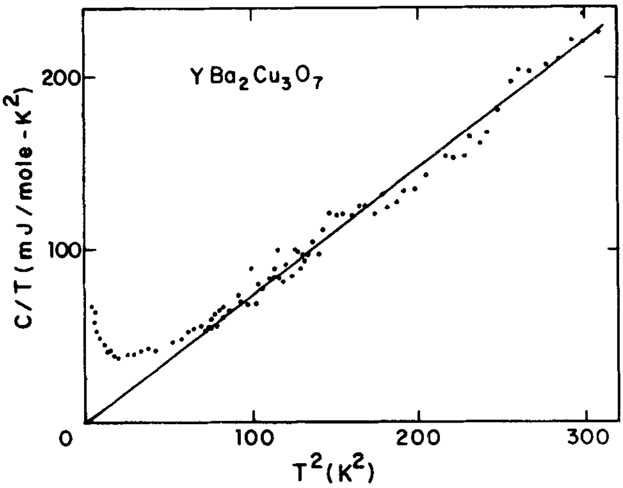

Figure 1. Low temperature heat capacity of $YBa_2Cu_3O_7$.

which is presumably not intrinsic to the sample. One of our starting materials CuO has 500 ppm of Fe present as impurity while Y_2O_3 was of 99·9% purity. The upturn at low temperatures could be due to the superparamagnetic behaviour of iron impurities giving rise to a Schottky-type anomaly at lower temperatures.* We therefore give greater weight to the data for $T \gg 9$ K. We may mention here that the superconductor $GdBa_2Cu_3O_7$ has an anomaly in the heat capacity at low temperatures due to the onset of antiferromagnetic order among the Gd spins at $T_N = 2{\cdot}24$ K (Willis *et al* 1987). At high temperatures, C/T is linear in T^2 and employing the Debye model of latice heat capacity we obtain a value of 325 K for the Debye temperature θ_D which is similar to that obtained for the isostructural Gd compound. It may be mentioned here that C/T is linear in T^2 for $T \lesssim \theta_D/50$ for most materials.

In the BCS model of superconductivity, heat capacity far below the transition temperature follows an exponential temperature dependence. For materials whose superconducting behaviour is well explained by the BCS model and which have a low transition temperature (in the liquid helium range), one can obtain an estimate of the coefficient of electronic heat capacity by extrapolating the normal state heat capacity to $T \rightarrow 0$ using the Debye approximation. Owing to the high transition temperatures of these recently discovered perovskite related oxides such a procedure is obviously untenable. Also it is not clear at present whether the BCS model is the appropriate theoretical description of the superconductivity of these materials. For example, in the resonating valence bond model (Anderson *et al* 1987) the density of states is not BCS-like and the low temperature specific heat is linear with temperature with a somewhat large metal-like γ. An extrapolation of our data obtained at temperatures above the upturn but below 8 K, gives a C/T at $T \rightarrow 0$ of about 25 mJ/mole K^2.

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* A fit of the above data in the temperature range 2 to 10 K to the form $C = \gamma T + \beta T^3 + A/T^2$ where A is the impurity term, gives the following values:

$\gamma = 20{\cdot}1$/mJ/mole-K^2, $\beta = 0{\cdot}47$ mJ/mole-K^4, $A = 207{\cdot}1$ mJ-K/mole.

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References

Anderson P W, Baskaran G, Zou Z and Hsu T 1987 *Phys. Rev. Lett.* **58** 2790

Bednorz J G and Muller K A 1986 *Z. Phys.* **B64** 189

Bryant C A and Keesom P H 1960 *Proc. VIIth Int. Conf. on Low Temp. Phys.* p 400

Cava R J, Batlogg B, vanDover R B, Murphy D W, Sunshine T, Siegrisr T, Remeika J P, Rietman E A, Zahurak S and Espinosa G P 1987 *Phys. Rev. Lett.* **58** 1676

Chu C W, Hor P H, Mong R L, Gao L, Huang Z J and Wang Y O 1987 *Phys. Rev. Lett.* **58** 405

Corak W S and Satterthwaite C B 1956 *Phys. Rev.* **102** 662

Dhar S K, Paulose P L, Grover A K, Sampathkumaran E V and Nagarajan V 1987 *J. Phys.* **F17** L105

Fisk Z, Thompson J D, Zirngiebl E, Smith J L and Cheong S W 1987 *Solid State Commun.* (in press)

Ganguly P, Mohanram R A, Sreedhar K and Rao C N R 1987 *Pramāna-J. Phys.***28** L321

Nambudripad N and Dhar S K 1987 TIFR Report (unpublished)

Uchida S, Takagi H, Kitazawa K and Tanaka S 1987 *Jpn. J. Appl. Phys. Lett.* (to be published)

Willis J O, Fisk Z, Thompson J D, Cheong S W, Aikin R M, Smith J L and Zirngiebl E 1987 *J. Magn. & Magn. Mater.* **67** L139

Wu M K, Ashburn J R, Torng C J, Hor P H, Meng R L, Gao L, Huang Z J, Wang Y Q and Chu C W 1987 *Phys. Rev. Lett.* **58** 908